AD-A035 677 FEDERAL AVIATION ADMINISTRATION WASHINGTON D C SYSTE--ETC F/G 5/10
HUMAN RESPONSE TO SOUND: THE CALCULATION OF PERCEIVED LEVEL, PL--ETC(U)
NOV 76 T H HIGGINS
UNCLASSIFIED FAA-RD-76-1 NL

1 OF 1
AD-A
035677

END
DATE
FILMED
3-25-77
NTIS

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A035 677

HUMAN RESPONSE TO SOUND

THE CALCULATION OF PERCEIVED LEVEL PLDB (NOISINESS OR LOUDNESS) DIRECTLY FROM PHYSICAL MEASURES

FEDERAL AVIATION ADMINISTRATION
WASHINGTON, D.C.

17 NOVEMBER 1976

Report No. FAA-RD-76-1

ADA035677

HUMAN RESPONSE TO SOUND: THE CALCULATION OF PERCEIVED LEVEL, PLdB (NOISINESS OR LOUDNESS) DIRECTLY FROM PHYSICAL MEASURES

Thomas H. Higgins

November 17, 1976

Final Report

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-76-1		

4. Title and Subtitle HUMAN RESPONSE TO SOUND: THE CALCULATION OF PERCEIVED LEVEL, PLdB (NOISINESS OR LOUDNESS) DIRECTLY FROM PHYSICAL MEASURES	5. Report Date NOVEMBER 17, 1976 6. Performing Organization Code 202-553-001
7. Author(s) THOMAS H. HIGGINS	8. Performing Organization Report No.
9. Performing Organization Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	10. Work Unit No. (TRAIS) 11. Contract or Grant No. In-House R&D, 202-553-001
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code 202-553-001

15. Supplementary Notes

16. Abstract The relationship between the perceived level, PLdB, of sound (loudness or noisiness) is shown to be a function of the sound pressure squared and the sound frequency squared, i.e. $PLdB = k\ p^2 f^2$. A logarithmic formula employing this basic relationship between perceived level and pressure and frequency has been developed and is found to be as accurate as the more complex methods currently in use, i.e. $PLdB = 14 + 20 \ Log_{10} P\ (\mu B) + 20 \ Log_{10} f\ (Hz)$ which is equal to the following: $PLdB = P(dB) - 60 + 20 \ Log_{10} F\ (Hz)$. The perceived level of an aircraft takeoff or landing is demonstrated to be equal, to the logarithmic sum of the perceived levels calculated using the above formula, for each octave band or 1/3 octave band, i.e. $PLdB = 10 \ Log_{10} [antilog_{10} PLdB_1/10 + antilog_{10} PLdB_2/10 \ldots + antilog_{10} PLdB_N/10]$

The results are found to be more accurate than the complex methods currently in use for the useful range of sound pressure levels and frequencies found to be associated with operational aircraft including helicopters, turbofan, turboprop and turbojet powered aircraft. This work, therefore, provides the systems engineer an easily understood and useful design and evaluation method. The formula developed clearly shows the design engineer and management personnel the relationship between the physical characteristics of an evolving system and its potential impact on human and community response.

17. Key Words	18. Distribution Statement
Sound Perceived Level Human Response Engineering Calculation Procedure Physical Measures	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	45	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

METRIC CONVERSION FACTORS

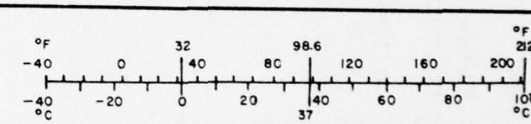
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Preceding page blank

ACKNOWLEDGEMENT

The generous help of James E. Mabry in providing aircraft flyover sound pressure levels and one-third octave band data for five flights each of Boeing 747, Beech 99, HU-1 Helicopter and simulated flights with a predominate 2 KHZ tone is gratefully acknowledged.

TABLE OF CONTENTS

Preceding page blank

LIST OF ILLUSTRATIONS

LIST OF TABLES

A UNIFIED APPROACH FOR DETERMINING HUMAN RESPONSE TO SOUND

SECTION I

INTRODUCTION

There are today numerous ways of determining human response to audible sounds (References 1, 2, and 3) which have evolved during the past 30 years. Because the calculation methods are different and also quite complex, they introduce problems to the user who must choose first an appropriate method for his purpose and then master the many steps required to measure and then calculate the desired human or community response to the often peculiar sounds the operational system generates.

The sound characteristics of the source whether impulsive, steady-state or combinations of both types, their definition and the semantic problems involved, have led to different methods of quantifying human reaction to different type sources. The variable nature of the atmosphere or path over which the sound is transmitted introduces variability but most of all the complicated characteristics of the receiver man viewed living alone or in communities has contributed most to the proliferation of measures and calculation procedures.

For optimum system design and operation, what is required is a unifying approach to determine the response of man and communities to all of the many sounds the operational system may generate.

It would be ideal if a single, simple approach to the known physical nature of sound could be used for the prediction of human reaction over the complete continuum of audible sounds no matter what their physical nature or their variation with time. To achieve this goal, the following work is dedicated.

To achieve the goal of developing a single method of predicting human response to all types of sounds, the method must predict with confidence the human reaction to both steady-state, impulsive sounds and their combination.

For impulsive sounds like sonic booms which have posed a difficult problem to quantify, the work contained in References 4 and 5 presents a simple solution. The human reaction to sonic boom is found to correlate with the peak overpressure (ΔP) divided by the amount of time required to reach that peak pressure or the rise-time (τ). The conclusion is that the human reaction or perceived level (PLdB) of an impulsive sound may be quantified as follows:

$$\text{Perceived Level, PLdB} = 55 + 20 \text{ Log}_{10} \left[\Delta P \text{ (PSF)}/\tau \text{ (sec)}\right] \qquad (1)$$

$$\text{Perceived Level, PLdB} = 21 + 20 \text{ Log}_{10} \left[\Delta P \text{ (N/M}^2)/\tau \text{ (sec)}\right] \qquad (2)$$

$$\text{Perceived Level, PLdB} = 1 + 20 \text{ Log}_{10} \left[\Delta P \text{ } (\mu B)/\tau \text{ (sec)}\right] \qquad (3)$$

The development of this formula for the perceived level of impulsive sound such as a sonic boom evolved as follows: Based on the 1965 work of Zepler and Harel (Reference 6) a memorandum (Reference 7) was written February 21, 1968, and discussed with the Operations and Engineering personnel of the U.S. Supersonic Transport (SST) Development Office urging the adoption of a Sonic Boom Index = $K\Delta P/\tau$. The objective was to communicate with aircraft designers the importance of another sonic boom signature parameter in addition to overpressure (ΔP), i.e., the interaction of rise-time (τ) and overpressure.

It was seen at that time that rise-time, i.e., the amount of time required to reach maximum peak overpressure in the above equation was of equal importance as overpressure, i.e., ΔP in affecting human reaction to sonic booms. This memorandum was followed by papers (References 8, 9, and 10) outlining the relationship between overpressure/rise-time and human response expressed by Figure 1 and subsequently adding the perceived levels based on the Edwards Air Force Base (AFB) Sonic Boom Test results. This was possible as a jury of Edwards AFB subjects found sonic booms with an average overpressure of 1.69 psf to be equivalent to the 105 PNdB flyover noise of a KC-135 aircraft (Reference 11).

Testing the hypothesis that average rise-time was equally important as average overpressure regarding the judged perceived level, the next step was to determine the rise-time associated with this judgement. A rise-time of 0.005 seconds was found to be appropriate based on

available Edwards AFB test data. The perceived level for other combination of $\Delta P/\tau$ could then be calculated based on the proposition that a doubling of overpressure or a halving of rise-time increased the perceived level by 6 PNdB.

It only remained to quantify this relationship as shown subsequently in Equation (1) to arrive at a very quick and simple approach to determining the perceived level of a sonic boom when overpressure and rise-time are known. The most important idea is that the Boom Index and Equation (1) hold the key to unlocking the required design criteria for supersonic aircraft.

The general formula for estimating the perceived levels of sonic boom was derived as follows:

> The Edwards AFB sonic boom test results indicate that a sonic boom doubled in perceived noise level (PNL) for each 6 PNdB increase. Therefore, the PNL of a sonic boom increases as a function of 20 Log_{10} X as when X doubles or is 2 then the PNL increases by 6 PNdB (20 times .3). The unknown X in the equation is of course the relationship of overpressure per unit time, i.e., $X = \Delta P/\tau$.

The subjects rating the sonic booms at Edwards judged the noise level of a boom averaging 1.69 psf overpressure (ΔP) and rise-time (τ) of 0.005 seconds as being equivalent to aircraft flyover noise of 105 PNdB. Expressing this information mathematically as a linear equation, we have:

$$\text{PNdB} = K + 20\ \text{Log}_{10}\ \Delta P/\tau$$

$$105 = K + 20\ \text{Log}_{10}\ 1.69/.005$$

$$105 = K + 20\ \text{Log}_{10}\ 338$$

$$105 = K + 20\ (2.5)$$

$$K = 105 - 50$$

$$K = 55$$

The general formula for estimating the perceived level of a sonic boom is, therefore:

$$\text{Perceived Level (PLdB)} = 55 + 20\ \text{Log}_{10} \Delta P\ \ (\text{PSF}/\tau\,(\text{SEC}) \qquad (1)$$

Equation (1) is plotted in Figure 1 employing an overpressure versus rise-time plot which yields the appropriate perceived level in decibels, PLdB.

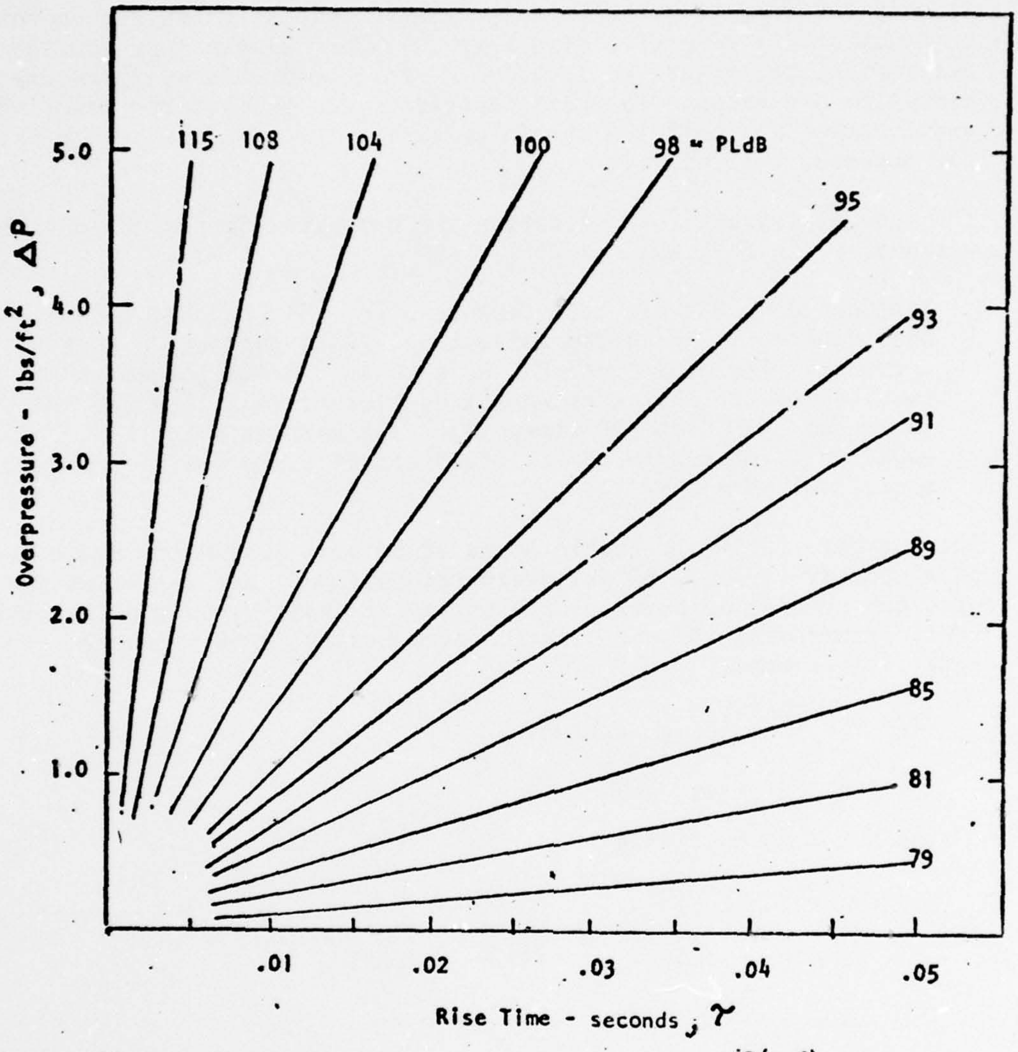


Chart employs the equation: $PLdB = 55 + 20 \log_{10} \frac{\Delta P(psf)}{\tau(SEC)}$

FIGURE 1. RELATIONSHIP BETWEEN OVERPRESSURE, RISE TIME AND THE PERCEIVED LEVEL, PLdB OF A SONIC BOOM

It was proposed that the equation for predicting human reaction to sonic boom be labeled PLdB, the perceived level in decibels, as outlined in the work of S. S. Stevens (Reference 3). The PLdB level may then be construed to be a measure of how people react to sonic booms. The Perceived Level, PLdB, measure has another advantage in that it solves a largely semantic problem. That is, how can one have an acceptable perceived noise level when by definition "noise" is "unwanted sound". As a result, an operating agency has the real problem plus a pseudo problem of trying to find an acceptable level of something that is by definition "unwanted".

To eliminate this problem in communication, it was proposed that the terminology perceived level (PLdB) be adopted. This was borne out by the test findings that there are indeed perceived levels, PLdB, of sonic booms which are acceptable to the people exposed to them. (References 4 and 5).

By studying the relationship expressed in the above equation, it also became apparent that a possible design window may be opened for supersonic aircraft operations over populated areas when the overpressure and rise-time conditions for acceptable sonic boom perceived levels are met.

Equation (1) was rewritten to accommodate other units of overpressure measurement. For example:

$$\text{Perceived Level (PLdB)} = 21 + 20 \text{ Log}_{10} \Delta P \text{ (N/M}^2\text{)}/\tau \text{ (SEC)} \qquad (2)$$

$$\text{Perceived Level (PLdB)} = 1 + 20 \text{ Log}_{10} \Delta P \text{ (}\mu\text{B)}/\tau \text{ (SEC)} \qquad (3)$$

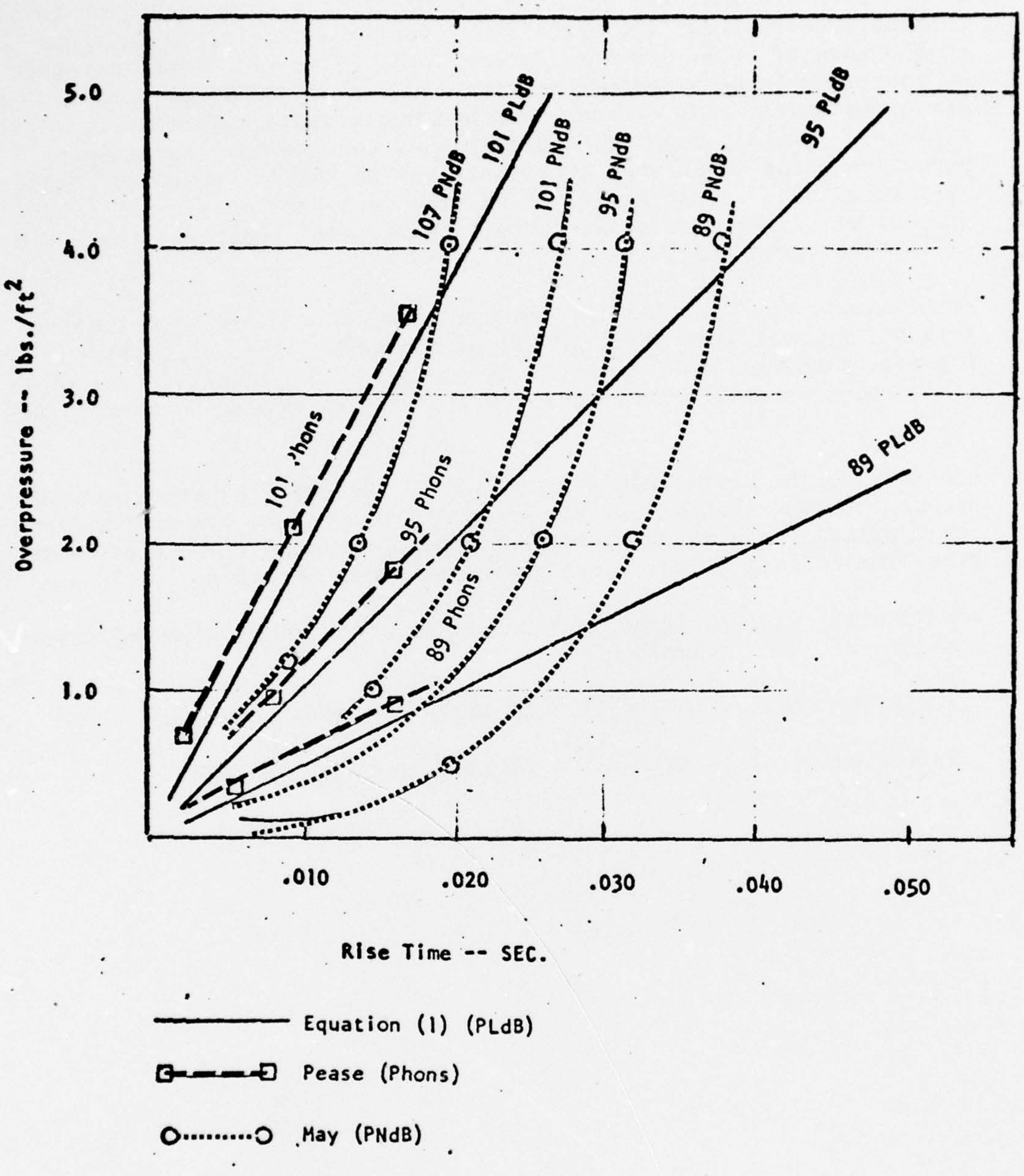


FIGURE 2. COMPARISON OF PREDICTION BY EQUATION (1) AND METHODS OF PEASE AND MAY

Figure 2 presents a comparison of the results obtained by using Equations (1), (2) or (3) which are identical but use different units of measurements, i.e., psf, N/M^2 and $\mu\beta$ respectively with the Fourier transform computer program calculations of Pease (Reference 12) based on the theory of Zepler and Harel (Reference 6).

The resulting estimated perceived levels are in good agreement, i.e., within 1 or 2 PLdB of each other in the important potential certification or design window that is in the 90 to 100 PLdB range.

Figure 2 also shows that the levels estimated using the method of May (Reference 13) vary considerably with the levels determined by the other methods.

The perceived level relationship with overpressure and rise-time expressed in Equation (1), (2), and (3) was also tested using the GASL traveling wave sonic boom simulation facilities. The tests using the magnitude estimation and acceptability judgement of 42 subjects are described in Reference 5. The results confirmed that Equations (1), (2) and (3) accurately predicted the perceived levels of the sonic booms ranging from 83 to 107 PLdB. The fifteen different sonic booms tested had pressure signatures which varied from 0.1 to 3.2 pounds per square foot (psf) of overpressure with rise-times (τ) of 4, 6, 8 and 12 milliseconds.

The accuracy of Equation (1) in predicting sonic boom perceived levels is shown in Figures 3 and 4, which present the comparison of psychophysical test results with the predicted PLdB level using Equation (1) (Reference 5). The perceived levels computed using Stevens Mark VII procedure are also shown.to be in agreement with the results calculated using Equation (1).

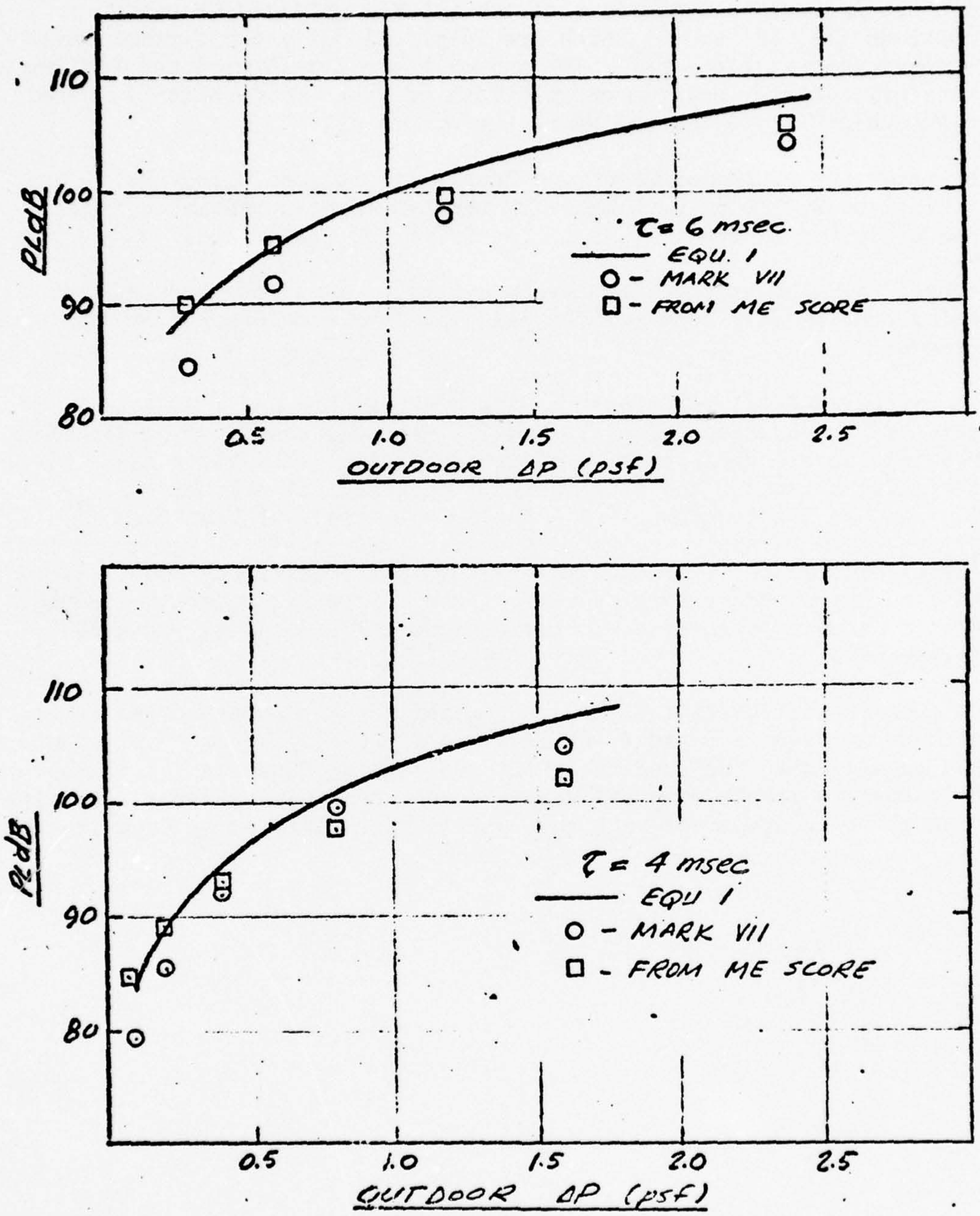


FIGURE 3. SUMMARY OF OUTDOOR RESPONSE DATA FOUR AND SIX MSEC RISE TIMES

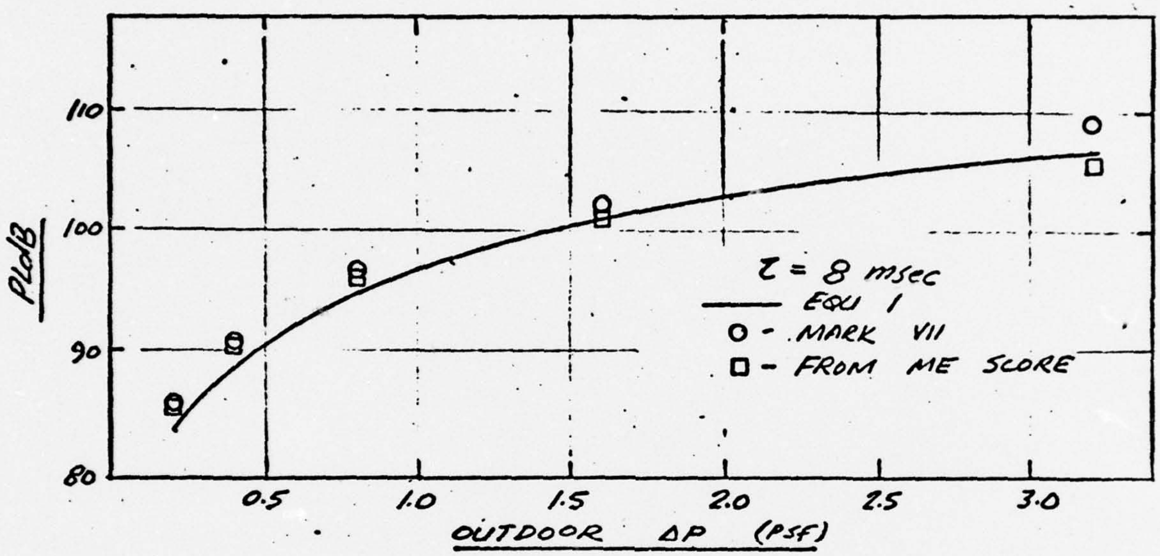


FIGURE 4. SUMMARY OF OUTDOOR RESPONSE DATA
EIGHT msec RISE TIME

SECTION II

APPROACH

The preceding work dealing with the perceived level of impulsive sounds (References 4, 5, 7, 8) led to the idea and the hypothesis to be tested here that there is a similar simple approach to quantifying steady-state sounds such as those produced by aircraft operations. Simply stated, it is based on the idea that human response to sound or its perceived level PLdB is a summation of the temporal function of the pressure changes (ΔP) from ambient and the amount of time (τ) required to reach the peak pressure. This time is one-fourth of the period (T) required to complete one cycle. It is during the time period T/4 seconds that each pressure wave reaches its maximum peak pressure (ΔP). Any pressure unit may be used such as pounds per square foot (psf), Newtons per square meter (N/m^2) or microbars (uB) which are equal to 1 $dyne/cm^2$.

It should be noted that the time to reach peak pressure T/4 seconds is also equal to 1/4f seconds or the reciprocal of four times the frequency.

Equation (3), $PLdB = 1 + 20 \; Log_{10} \; \Delta P \; (\mu\beta)/\tau \; (Seconds)$, for

impulsive sound may, therefore, be rewritten substituting for either T/4 seconds or 4f (Hz) yielding several new equations which may be tested for accuracy in predicting the perceived level of steady state-sounds:

$$PLdB = 1 + 20 \; Log_{10} \; [\Delta P \; (\mu\beta) / \; T/4 \; (Seconds)] \tag{4}$$

and

$$PLdB = 1 + 20 \; Log_{10} \; [\Delta P \; (\mu\beta) \; 4f \; (Hz)] \tag{5}$$

and

$$PLdB = 13 + 20 \; Log_{10} \; [\Delta P \; (\mu\beta) \; f \; (Hz)] \tag{6}$$

as $20 \; Log_{10} = 12$ which is added to the constant 1 and eliminates 4 from the variable f.

Equation (6) then re-states the hypothesis that there is a direct relationship between the interaction of pressure and frequency and the perceived level of steady-state sounds such as those generated during aircraft operations. This is also true of Equations 1, 2 and 3 for calculating the perceived level of impulsive sounds such as sonic booms generated by supersonic aircraft. The perceived level of the impulsive sound is also directly related to the pressure and frequency content of the sonic boom spectra. This is based on the inverse relationship of the rise-time (τ) to the perceived level because the greater the rise-time the less high frequency content of the audible boom and the shorter the rise-time the greater its high frequency content. Therefore, this last impulsive sound is perceived as being louder or noisier for the reason that doubling the frequency content of the boom adds 6dB (i.e. 20 Log_{10} f) even though the physical measured pressure remains the same.

Equation (6) may be stated in general terms and logarithmic form as follows:

Perceived Level, $PLdB = k + 20 \ Log_{10} \ P(\mu B) + 20 \ Log_{10} \ f \ (Hz)$ (7)

As the formula for dB may be written as $dB = 74 + 20 \ Log_{10} \ P \ (uB)$, when dB formula's numerator is divided by the denominator 0.0002 uB, then $dB - 74 = 20 \ Log_{10} \ P \ (\mu B)$. Therefore,

Perceived Level, $PLdB = k + P(dB) - 74 + 20 \ Log_{10} \ f \ (Hz)$ (8)

The absolute value of PLdB is determined by the frequency selected as a standard for psychoacoustic, i.e., psychophysical scaling purposes. For example: When 1000 Hz is used as the standard comparison frequency, then the perceived level, PLdB is equal to the physical measure of dB at all pressure levels having a frequency of 1000 cycles per second. The value of k will, therefore, vary as the standard frequency for psychoacoustic, i.e., psychophysical scaling purposes is changed. For example: When 1000 Hz is used as the standard at 100 dB then:

$PLdB = k + P(dB) - 74 + 20 \ Log_{10} \ 1000 \ (Hz)$

$100 = k + 100 - 74 + 30$

$k = 14$ (when 1000 Hz is selected as the standard frequency) (9)

When 3150 Hz is selected as the standard then k in Equation (9) is equal to 4. The absolute value of the perceived level is, therefore, 10dB lower when the psychoacoustic scaling is based on a standard frequency of 3150 Hz compared to the perceived level obtained when the psychoacoustic standard selected is 1000 Hz.

The formula selected for testing herein is based on a standard frequency of 1000 Hz (as in the Part 36 tables used by the FAA in certification of aircraft noise) with a k value of 14, therefore, the perceived level, PLdB formula to be tested is as follows:

$PLdB = 14 + dB - 74 + 20 \ Log_{10} \ f \ (Hz)$ (10)

$PLdB = P(dB) - 60 + 20 \ Log_{10} \ f \ (Hz)$ (11)

Equation (11) is also equal to the following equations which are of course mathematical identities:

$$PLdB = 20\ Log_{10}\left[\frac{P(\mu B)}{.0002(\mu B)}\ \frac{f(Hz)}{1000(Hz)}\right] \qquad (11a)$$

$$PLdB = 10\ Log_{10}\left[\frac{P(\mu B)}{.0002(\mu B)}\ \frac{f(Hz)}{1000(Hz)}\right]^2 \qquad (11b)$$

$$PLdB = 10\ Log_{10}\left[10^{1.4}\ P^2(\mu B)\ f^2(Hz)\right] \qquad (11c)$$

It can be seen by examining equation (11a) that the absolute level of PLdB is determined by two reference levels one for pressure; .0002uB and the other for frequency, 1000Hz.

Equations (11b) and (11c) make clear that the perceived level of sound is a function of pressure squared and frequency squared or an energy relationship.

The perceived level PLdB relationship with sound pressure level and frequency per one-third octave bands is presented in Table I as computed using Equation (11).

It is interesting to note that Equations (6) and (11) differ solely in the value of k being 13 versus 14 or a 1 dB difference. Each equation was derived independently. Equation (6) was derived from the impulsive sound formula number (3). While Equation (11) was derived from the fact that the perceived dB level must equal the physical dB level when it occurs at the standard frequency.

Equation (11) is chosen for testing herein as it is the simplest and most precise way of relating the psychophysical to the physical characteristics of sound pressure and frequency.

The PLdB is determined first in each of the 24 one-third octave bands (or 8 octave bands if data is in octave bands) using Equation (11) and the appropriate mid-frequency and P(dB), unweighted sound pressure level. The PLdB for the aircraft flyover is determined by obtaining the logarithmic sum of the PLdB, perceived levels calculated in each one-third octave band.

i.e.,

$$PLdB = 10 \, Log_{10} \left[antilog_{10} \frac{PLdB_1}{10} + antilog_{10} \frac{PLdB_2}{10} \ldots + antilog_{10} \frac{PLdB_n}{10} \right] \qquad (12)$$

The Perceived Level, PLdB contours computed by Equation (11) with 1000 Hz as the standard frequency which are tested in this report are presented in Figure 5.

The perceived levels calculated using Equation (11) are presented in Table I.

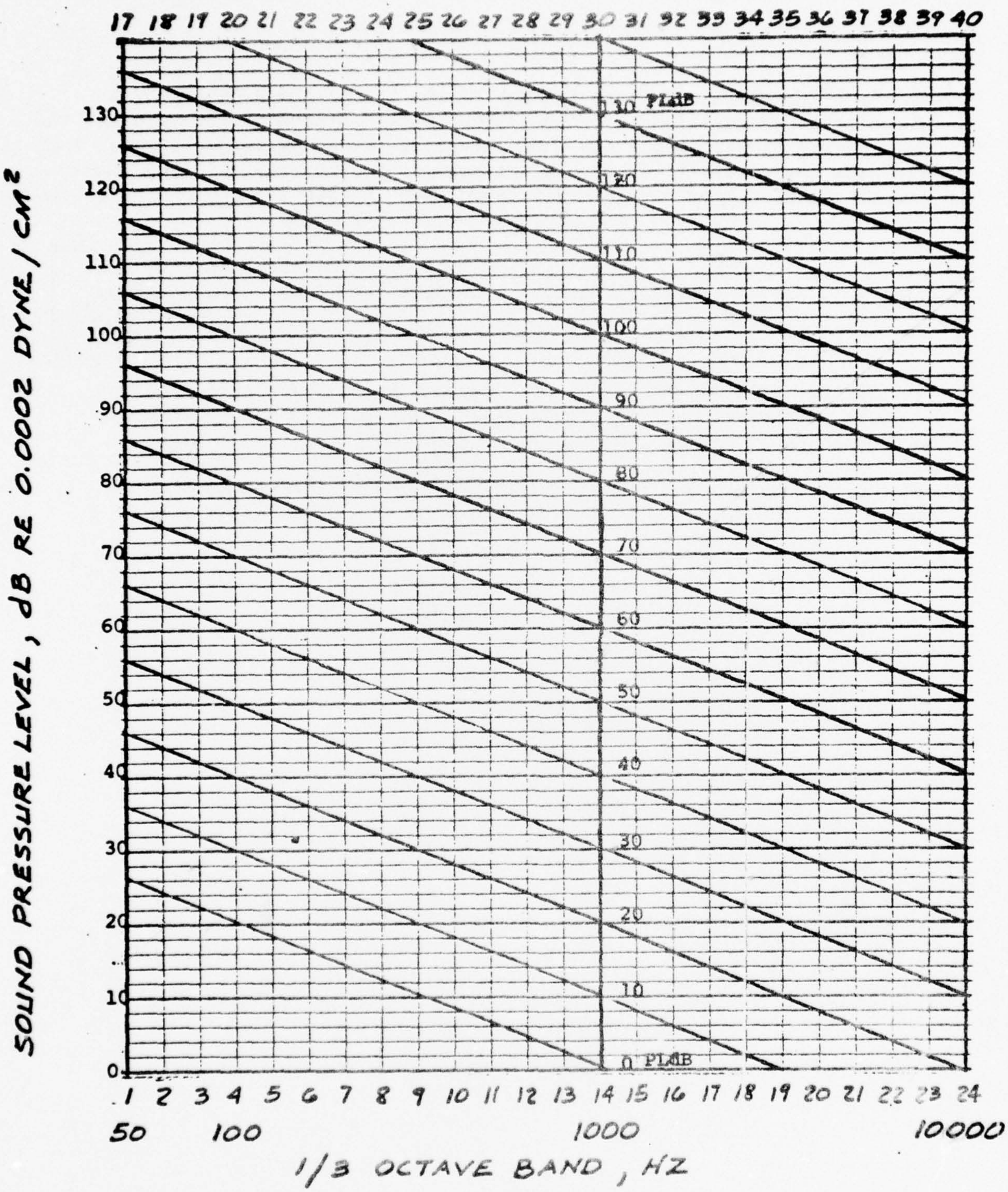


FIGURE 5. PERCEIVED LEVEL, PLdB, CONTOURS WITH 1000Hz AS THE STANDARD FREQUENCY. PLdB = P(dB) - 60 + 20 Log_{10} f(Hz), TESTED IN THIS REPORT.

	BAND CENTER FREQUENCY f (Hz)																							
SPL-(dB)	50.	62.5	80	100	125	160	200	250	315	400	500	630	800	1,000	1,200	1,600	2,000	2,500	3,100	4,000	5,000	6,300	8,000	10,000 Hz
150	124	126	128	130	132	134	136	138	140	142	144	146	148	150	152	154	156	158	160	162	164	166	168	170
140	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142	144	146	148	150	152	154	156	158	160
130	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142	144	146	148	150
120	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140
110	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130
100	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120
90	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
80	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
70	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
60	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
50	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70
40	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
30	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50

TABLE 1. PERCEIVED LEVEL, PLdB, RELATIONSHIP WITH SOUND PRESSURE LEVEL AND FREQUENCY PER ONE-THIRD OCTAVE BANDS

SECTION III

RESULTS

What determines how valid and useful a particular engineering calculation procedure is in accurately expressing the perceived level of aircraft operations depends on the extent that it corresponds or correlates with direct judgement results. Therefore, the procedure used to determine the performance of dB(A), PNdB, PLdB (Mark VII) and PLdB (Equations 11 and 12) was to calculate the Pearson r* correlation between the calculated levels and the logarithm of the average magnitude estimation judgements of thirty-five persons. In order to provide an adequate test a diverse group of aircraft was selected. They included Boeing 747, Beech 99, HU-1 Helicopters and a V/STOL simulation with a strong 2 KHz tone so as to include turbofan and turboprop powered conventional aircraft, turbine powered helicopters and simulated aircraft with a strong predominate tone. All aircraft flyovers were judged at five levels and included takeoff and approach operations. This mix of aircraft, levels and operations provides an adequate test of the various calculation procedures due to the diverse spectral, temporal, tone, and onset characteristics of the sounds which will be evaluated.

The complete details regarding experimental procedures are contained in Reference 14. The purpose here is to determine the correlation of the perceived levels calculated at five different levels for each of four different aircraft with the direct judgement results.

The object was to quantify this relationship by using the Pearson r_{xy} correlation between the various engineering calculation procedures x and the magnitude estimation judgements y for each aircraft and for all aircraft combined. This was done at five levels, i.e., 57, 61, 65, 69 and 73 dB(A) which may be experienced by persons in their homes corresponding to out-of-doors levels ranging from approximately 77 to 93 dB(A). In like manner, the Pearson r_{xy} correlation between the various calculation procedures and the judgements for all four aircraft combined quantifies how well each calculation procedure does for diverse types of aircraft over a range of perceived levels.

Next, the linear regression equation* for each aircraft examined alone and for all aircraft combined was determined and plotted. In this way, the exact relationship between the calculation procedures and the human judgements has not only been quantified for each aircraft and all aircraft combined but presented graphically covering all levels and showing clearly the relationship of the different calculation procedures to the human judgements for each aircraft viewed individually and for all aircraft combined over the range of sounds from aircraft operations most likely to be experienced by persons in their homes.

*See Handbook of Chemistry and Physics, 45th Edition Published by the Chemical Rubber Co; Pg. A-164 for example of (product-moment) co-coefficient of correlation and regression

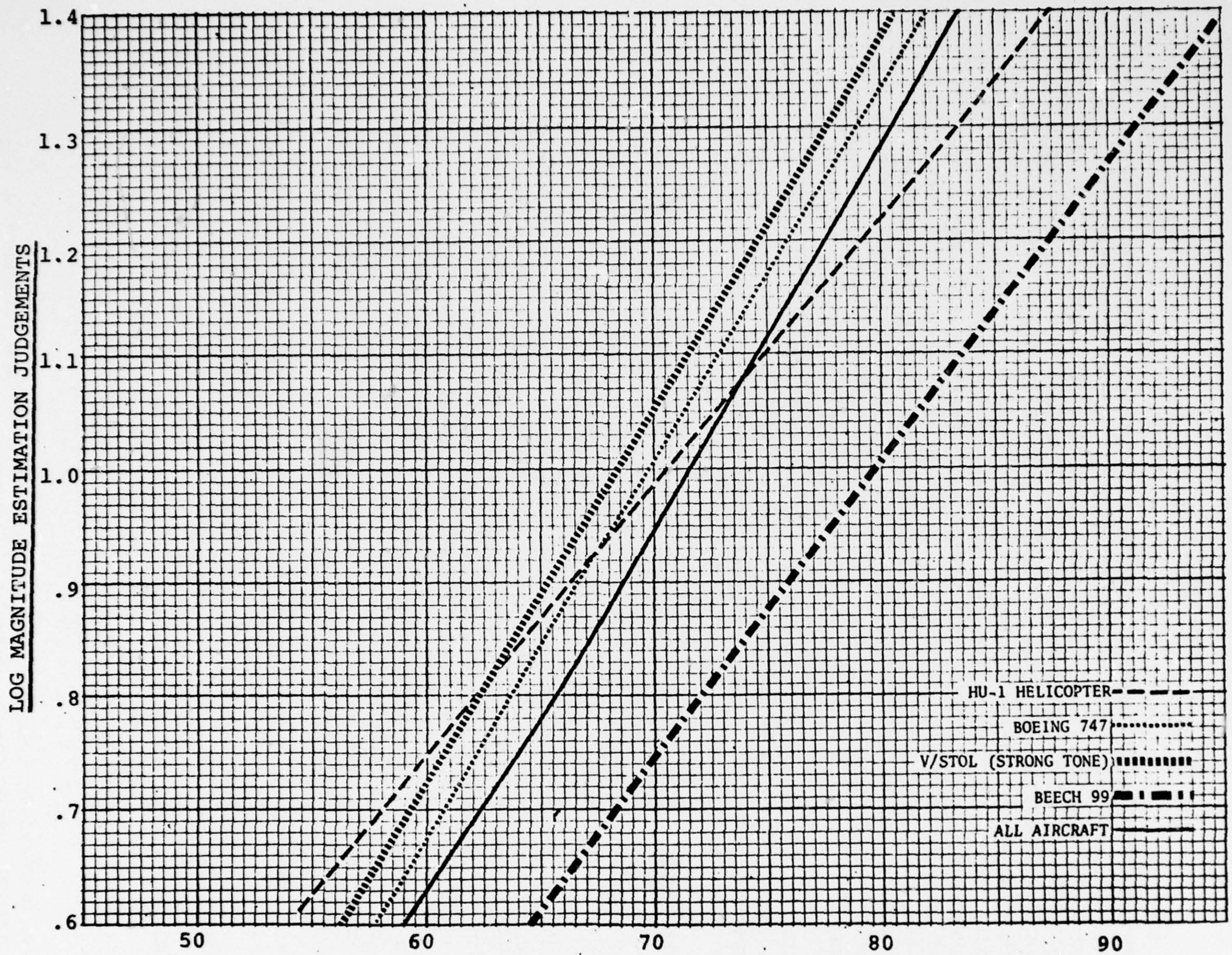


FIGURE 6. THE RELATIONSHIP BETWEEN THE dB(A) CALCULATION PROCEDURE AND MAGNITUDE ESTIMATION JUDGEMENTS FOR EACH AIRCRAFT AND FOR ALL AIRCRAFT.

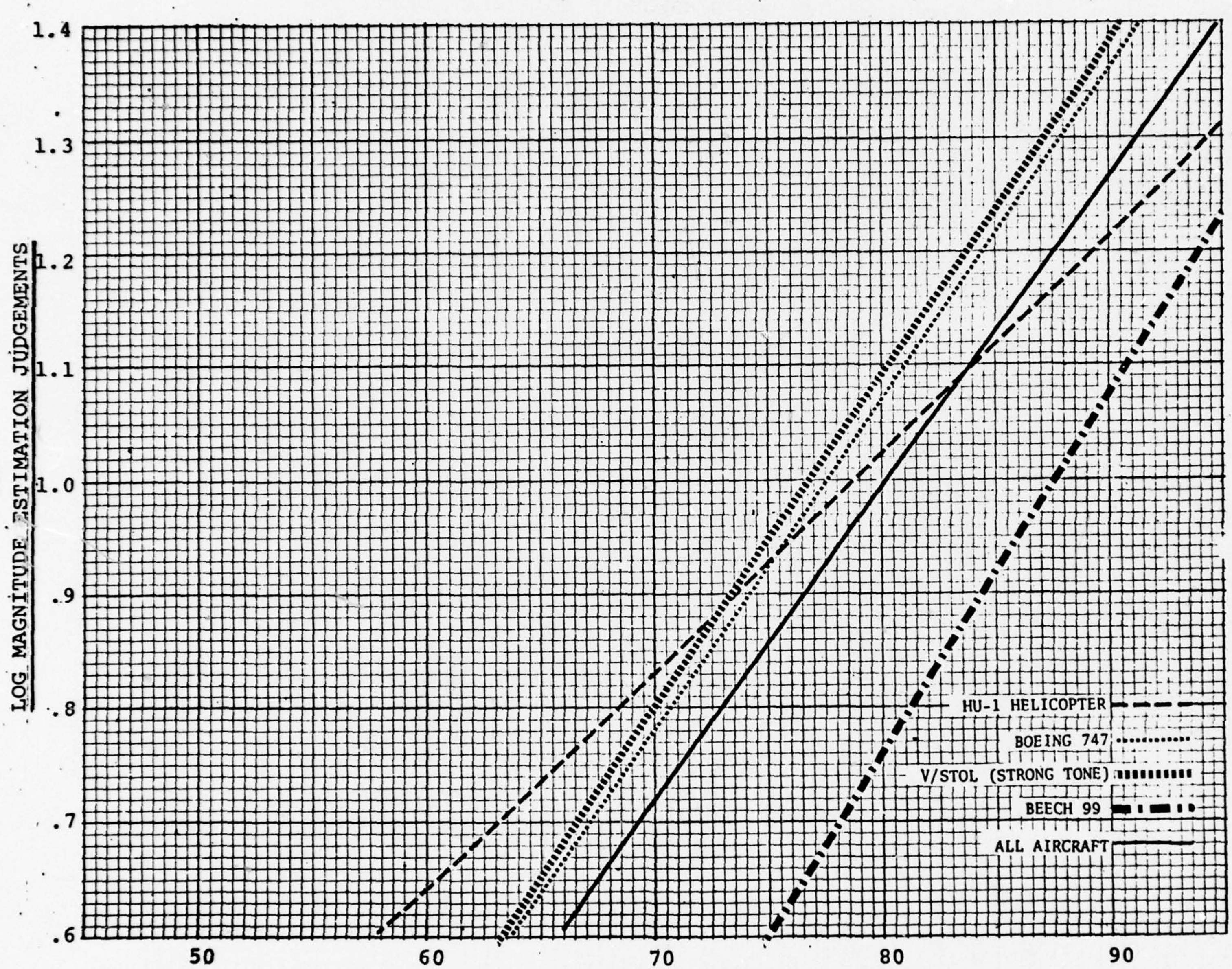


FIGURE 7. THE RELATIONSHIP BETWEEN THE PNdB CALCULATION PROCEDURE AND MAGNITUDE ESTIMATION JUDGEMENTS FOR EACH AIRCRAFT AND FOR ALL AIRCRAFT.

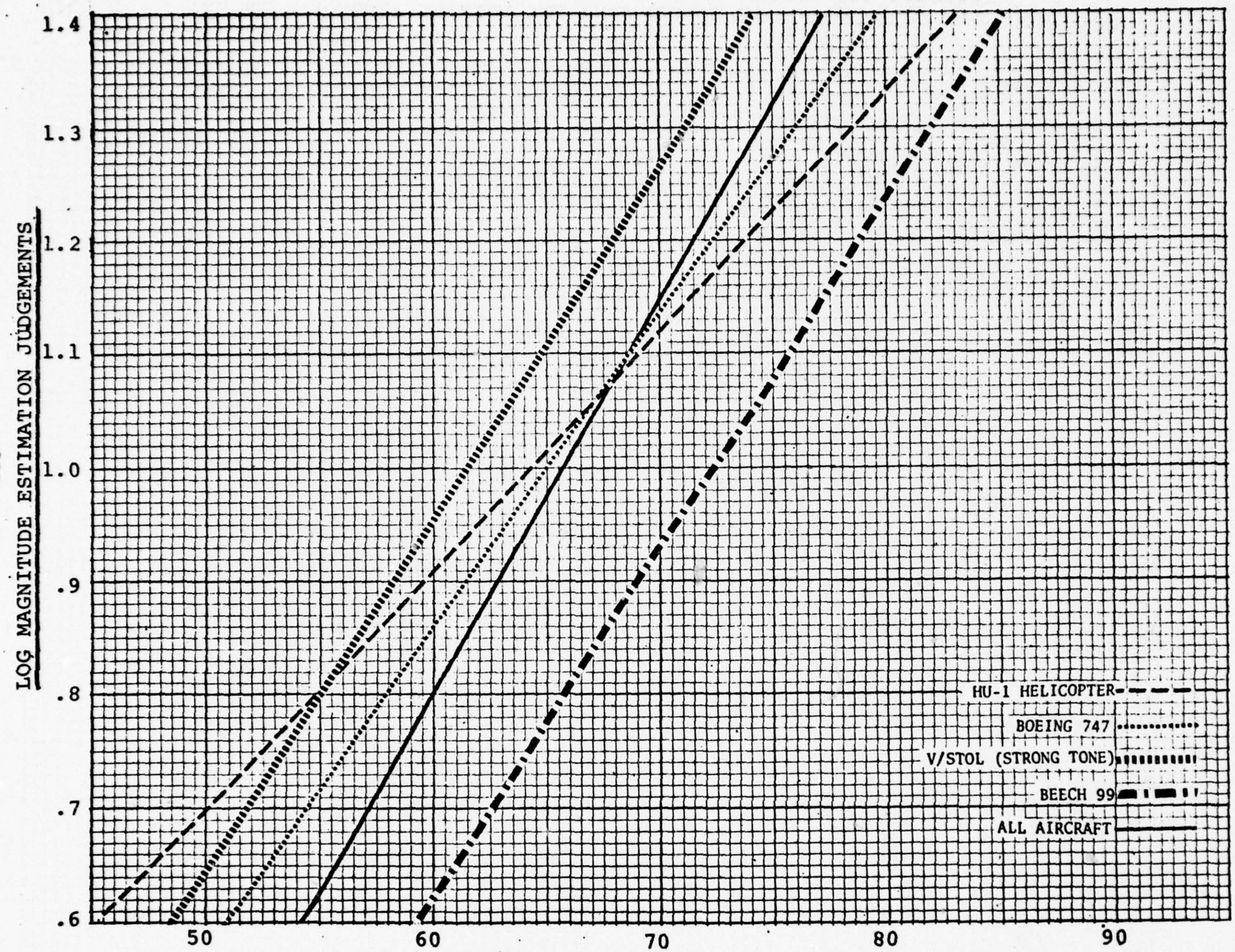


FIGURE 8. THE RELATIONSHIP BETWEEN THE PLdB (MARK VII) CALCULATION PROCEDURE AND MAGNITUDE ESTIMATION JUDGEMENTS FOR EACH AIRCRAFT AND FOR ALL AIRCRAFT

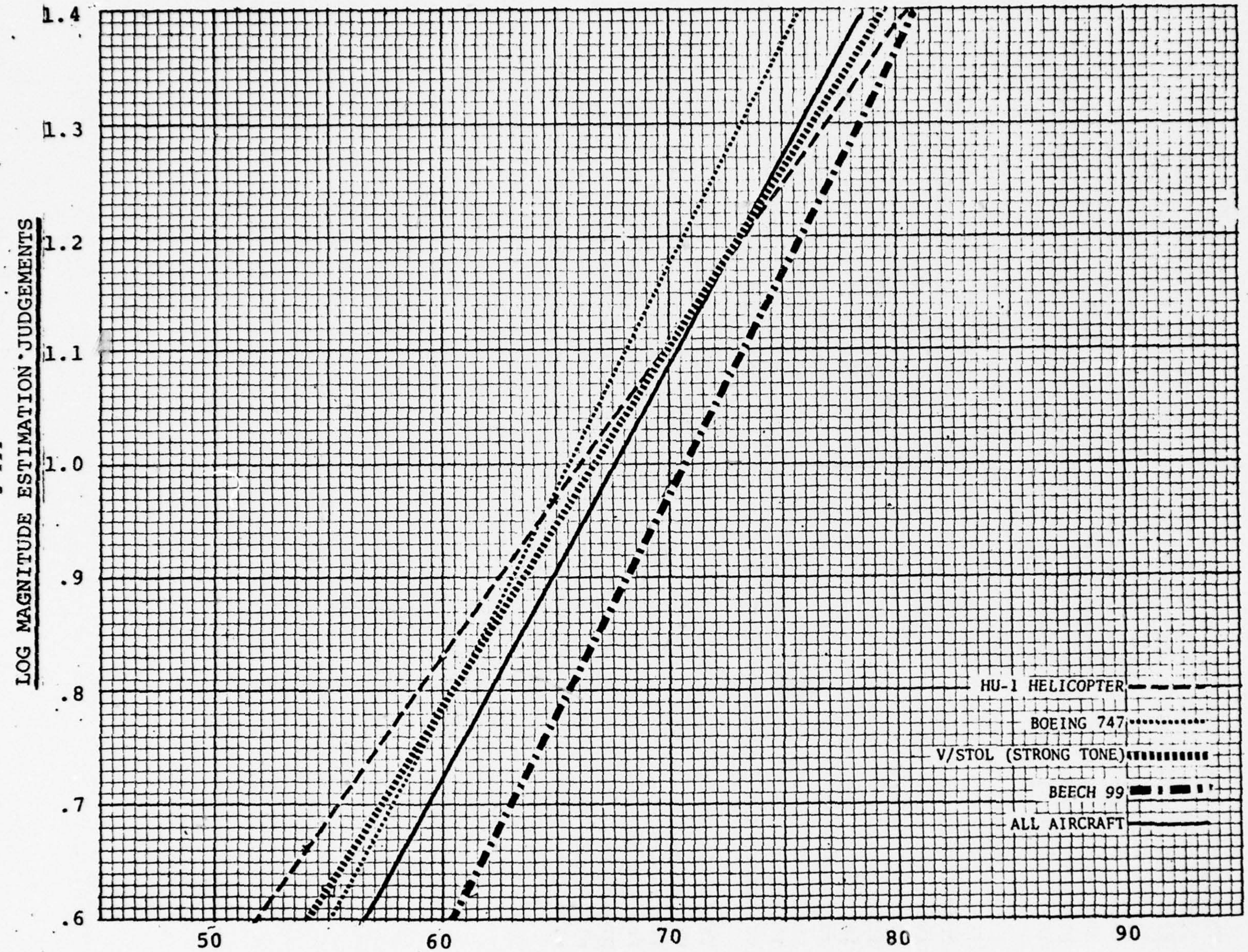


FIGURE 9. THE RELATIONSHIP BETWEEN THE PLdB (EQUATIONS 11 & 12) CALCULATION PROCEDURE AND MAGNITUDE ESTIMATION JUDGEMENTS FOR EACH AIRCRAFT AND FOR ALL AIRCRAFT.

The results are presented graphically in Figures 6, 7, 8, and 9. Each figure presents a different engineering calculation procedure PNdB, PLdB (Mark VII), dB(A) and the calculation procedure developed and tested in this report PLdB (Equations 11 and 12). The correlation of each procedure with the human judgement may be seen for each aircraft and for all aircraft combined. How well the calculation procedures predict or measure human response in terms of annoyance or the perceived level of noisiness or loudness may also be seen clearly at all levels.

These results viewed graphically in Figures 6 through 9 are quantified first for all aircraft combined in Table II. These are the Pearson r_{xy} correlation coefficients which express the degree of relationship between the calculation procedures, x and the human judgements y. This correlation r_{xy} has a possible range from -1.0 to 1.0 with 1 being perfect correlation and 0 showing no correlation between the variables of interest. The Pearson r_{xy} correlation coefficient is an extremely powerful statistic being rated at 100 percent power in terms of statistical power in showing relationship. It is, therefore, most appropriate for this analysis of how well each procedure measures the perceived level of aircraft during approach to landing and takeoff operations.

Table II discloses how well each engineering calculation procedure expressed the judgements of thirty-five persons exposed to five different levels of sound for each of four very different aircraft. The Pearson r_{xy} correlation coefficient quantifies the relationship between procedures and the judgements. PNdB has the lowest correlation of .75 with higher correlation of .82 for PLdB (Mark VII) and of .80 for dB(A) with the highest correlation found for PLdB (Equations 11 and 12) of .90.

TABLE II. CORRELATION, r_{XY} OF ENGINEERING CALCULATION PROCEDURES, X WITH HUMAN JUDGEMENT RESULTS, Y FOR ALL AIRCRAFT:

BOEING 747, BEECH 99, HU-1 HELICOPTERS AND V/STOL WITH STRONG TONE

CALCULATION PROCEDURE	PEARSON r_{xy} ALL AIRCRAFT*	AMOUNT OF VARIABILITY, r^2_{xy} ACCOUNTED FOR BY PROCEDURE
PNdB	.75	56%
PLdB (Mark VII)	.82	67%
dB(A)	.80	64%
PLdB (Eqs. 11 & 12)	.90	81%

*N.B. All correlations are statistically significant at the 1% level.

The last column of Table II presents a measure of the amount of variability, λ^2xy, in the relationship between the calculation procedures and human judgements of these diverse aircraft sounds which is accounted for by the calculation procedure. PNdB accounts for 56 percent, PLdB (Mark VII) for 67 percent, dB(A) for 64 percent and PLdB (Equations 11 and 12) accounts for 81 percent of the variability. These results are a very surprising and highly significant outcome because they validate a new engineering calculation procedure derived a priori both from impulsive sound roots contained in Equation (3) and also derived by a new psychophysical calculation procedure used in originating Equations (11) and (12). It validates the energy relationship between sound and its perceived level as clearly disclosed by Equations (11b), (11c) and (12). The perceived level of a sound is a logarithmic function of sound pressure squared and the frequency of the sound squared. This statement is true of all sound viewed as a continuum running from impulsive type sound such as produced by supersonic flight i.e., sonic booms as expressed mathematically in Equation (3) through steady-state sound such as produced by aircraft takeoff and approach to landing operations as expressed in Equations (11) and (12).

The above results are the severest possible test of an engineering calculation procedure as it shows how well the procedure measures widely differing aircraft flyover sounds at five levels which span low, medium and high perceived levels which may be experienced by persons in their homes.

All of the correlations contained in Table II are statistically significant at the one-percent level signifying a valid relationship existing between engineering calculation procedures and human judgements at the 99 percent level of confidence.

The perceived level of each flyover as calculated by the different engineering calculation procedures and the human judgement results are contained in Appendix B.

SECTION IV

DISCUSSION

The high Pearson r_{xy} correlation found of .90 or r^2_{xy} of .81 indicates that PLdB (Equations 11 and 12) accounts for 81 percent of the variability between human judgement results and the flyover sounds. This is a surprising and significant result considering the diverse nature of the flyover sounds for the four different aircraft at five levels which may be heard in persons homes near airports between 50 and 80 PLdB. This high correlation is based solely on the pressure and frequency content of the flyover signals. The correlation increases with the incorporation of a duration correlation computed as currently outlined in FAA Part 36 regulations.

These results confirm the energy relationship between the perceived level of a sound and the logarithmic sum of the sound pressure squared and frequency squared as clearly seen when Equation (11) is expressed as in Equations (11b) and (11c).

Equation (11) was first derived, as Equation (6), from Equation (3) an equation which had been shown in Reference 3 to correctly calculate the perceived level of impulsive sounds such as a sonic boom. It was then derived independently by stating mathematically the psychophysical hypothesis that the perceived level of a sound is equal to its sound pressure level at the standard frequency. These two independent approaches resulted is Equations (6) and (11) which differ by only 1 dB. These equations, (3) for impulsive sound and (6) and (11) for steady-state sound, verify by their high correlation with human judgement results the energy relationship between the perceived level of a sound and the logarithmic sum of the sound pressure and frequency squared. All sound, therefore, must be viewed as a continuum whether labled impulsive or steady-state sound by arbitrary definition.

It is, of course, necessary to obtain the perceived level of steady-state sound in all octave or one-third octave bands as stated in Equation (12). Equation (12) is also an energy summation which is necessary because of the manner in which steady-state sounds are recorded and analyzed. Impulsive sounds and steady-state sounds are therefore identical in that their perceived levels are directly related to the logarithmic sums of pressure squared and frequency squared, i.e., an energy relationship. When overpressure versus time or pressure signature recordings are made of impulsive sounds like sonic booms where peak overpressure, ΔP and rise time, τ are readily available then Equation (3) may be used. Otherwise the perceived level of impulsive sounds may be determined using Equations (11) and (12) just as for steady-state sound where the tape

recorded impulsive sound may be analyzed so that the sound pressure levels, flat or unweighted, are determined in each one-third octave band. The sampling time of course must differ due to the less than one second or a half second duration of the impulsive sound.

The Perceived Level, PLdB, contours calculated by the general Equation (9) vary with the standard comparison frequency chosen. This is the frequency selected for the standard sound which is used during psychophysical experiments to obtain comparison judgements from test subjects regarding the noisiness or loudness of other sounds.

Figure 5 presents the Perceived Level Contours which were tested and discussed in this report. They are based on a standard frequency of 1000 Hz and therefore employ the relationship expressed in Equation (11) that Perceived Level, PLdB = P(dB) - 60 + 20 Log_{10} f (Hz). This, of course, in terms of the general Equation (9) based on 1000 Hz standard equals: PLdB = 14 + 20 Log_{10} P(μB) + 20 Log_{10} f (Hz).

Similar contours may be constructed based on any frequency selected as a standard frequency such as 3150 Hz. These contours would employ the relationship expressed as follows:

$$\text{PLdB} = \text{P(dB)} - 70 + 20\ \text{Log}_{10}\ f\ (\text{Hz}) \qquad (13)$$

which is in turn equal to the following:

$$\text{PLdB} = 4 + 20\ \text{Log}_{10}\ P\ (\mu\text{B}) + 20\ \text{Log}_{10}\ f\ (\text{Hz}) \qquad (14)$$

It is instructive to demonstrate that Equation (11) yields the same results as its longer form Equation (7). As any sound pressure level tested at the standard frequency selected, which is 1000 Hz in this example, will be definition equal the perceived level, then for example:

$$\begin{aligned} 100\ \text{dB at 1000 Hz} &= \text{P(dB)} - 60 + 20\ \text{Log}_{10}\ f\ (\text{Hz}) \\ &= 100 - 60 + 20\ \text{Log}_{10}\ (1000) \\ &= 100 - 60 + 20\ (3.0) \\ &= 100 - 60 + 60 \\ &= 100\ \text{PLdB} \end{aligned}$$

Using Equation (9) and the fact that 100 dB = 20 μB results in the following:

$$\begin{aligned} 100\ \text{dB at 1000 Hz} &= 14 + 20\ \text{Log}_{10}\ P(\mu\text{B}) + 20\ \text{Log}_{10}\ f\ (\text{Hz}) \\ &= 14 + 20\ \text{Log}_{10}\ 20 + 20\ \text{Log}_{10}\ 1000 \end{aligned}$$

$$= 14 + 20\ (1.3) + 20\ (3.0)$$

$$= 14 + 26 + 60$$

$$= 100 \text{ PLdB}$$

The perceived level contours based on 1000 Hz and 3150 Hz respectively as the standard frequency, differ by 10 dB with contours based on the higher selected standard frequency yielding the lower perceived level contours. This helps to explain in part why there is a constant difference between PNdB calculations based on 1000 Hz and PLdB (Mark VII) based on 3150 Hz which are found to be lower.

Figure 10 compares the PLdB (Equations 11 and 12) contours of Figure 5 with PNdB and PLdB (Mark VII) contours of equivalent perceived levels. It is interesting to note that their is general agreement between PLdB (Equations 11 and 12) and PLdB (Mark VII) in the low frequency range below 1000 Hz and with PNdB above 1000 Hz and extending to approximately 4000 Hz in terms of absolute level.

In terms of general trend of contour and disregarding absolute level there is general agreement of contour shape between calculation procedures in the low frequency range especially between 50 and 500 Hz and between 1000 and 4000 Hz.

The above examples demonstrate that the absolute level of calculated psychoacoustic measures such as PNdB, PLdB (Mark VI), PLdB (Mark VII) and PLdB (Equations 11 and 12), depend partly on the standard frequency on which they are based. That is, the frequency selected as the standard comparison sound which was used during psychophysical tests to obtain judgements from subjects in laboratories regarding the noisiness or loudness of other sounds, and ultimately to invent a psychoacoustic measurement unit and a measurement system, determined the absolute value of the perceived levels ultimately calculated.

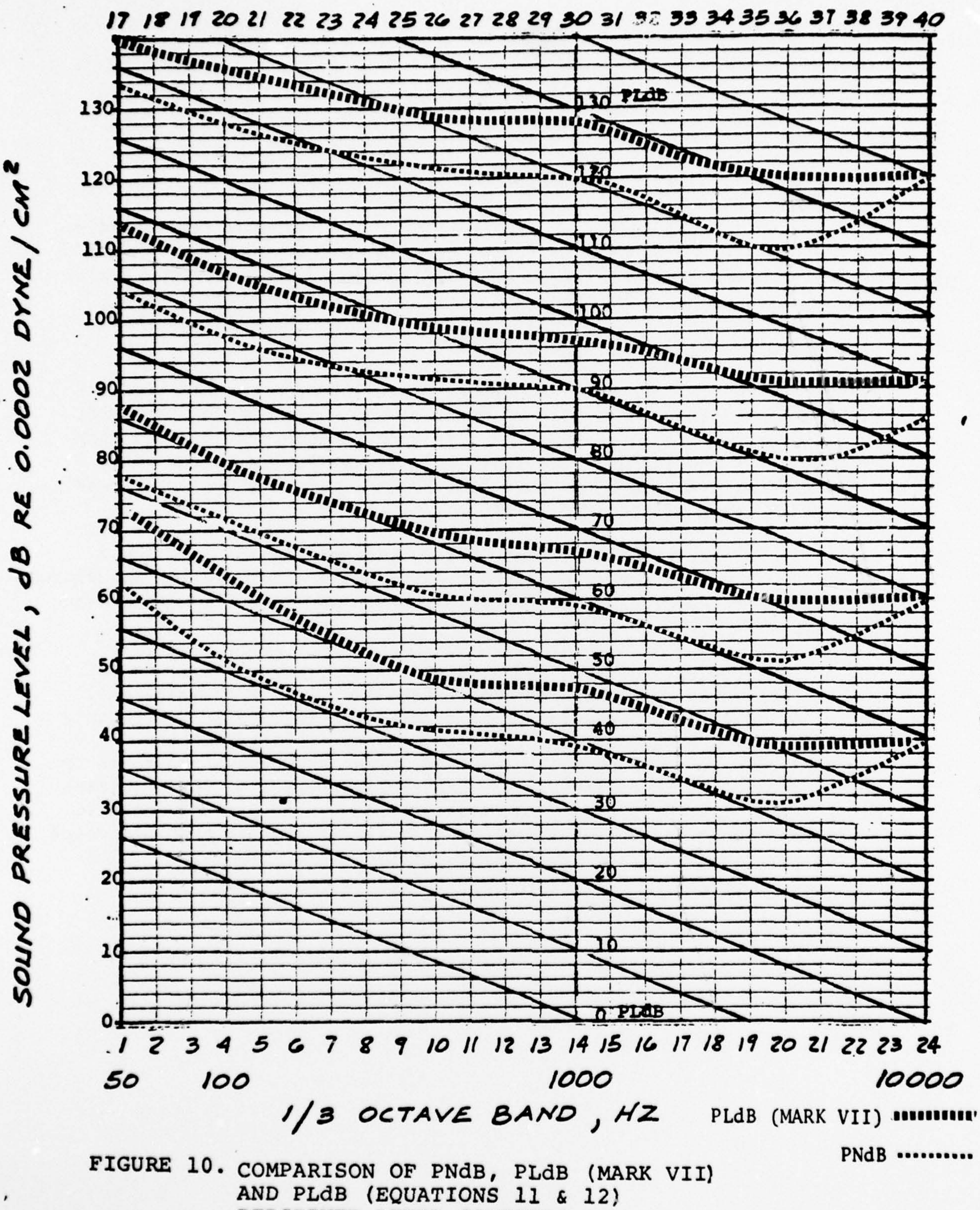


FIGURE 10. COMPARISON OF PNdB, PLdB (MARK VII) AND PLdB (EQUATIONS 11 & 12) PERCEIVED LEVEL CONTOURS

The perceived level, PLdB Equation (11) relationship with sound pressure level and frequency, shown as contours of equal perceived level in Figure 5 and quantified in Table I, is useful in the operational range of sound pressure levels associated with nearby aircraft operations as perceived in one's home. That is, above the practical threshold which may be thought of as being approximately 30 PLdB for indoor and night-time conditions in one's home. PLdB (Equation 11 and 12) has demonstrated the precision to express the perceived levels of noisiness or loudness of aircraft sounds above the practical threshold. In like manner, it has not been tested at the upper limits defined by the pain level of approximately 130 PLdB. It has been tested and is useful in the practical operating levels associated with sounds perceived in and about one's home associated with aircraft operations.

An additional consideration is the frequency range over which Equation (11) is operationally useful. The range of useful frequencies tested herein cover the customarily measured 24 one-third octave bands as shown in Figure 5 and Table I. This is borne out examining the spectra contained in Appendix A and by the high correlation found between human judgement results and PLdB (Equations 11 and 12) for four very different aircraft spectra.

It is a principle of nature explained by the science of physics that the high frequencies attenuate rapidly with distance from the source while low frequencies do not attenuate as rapidly. As a result, the greater the distance from the source the more important the low frequencies become for they retain higher sound pressure levels and therefore have the most impact on the perceived level of the aircraft flyover. The perceived level of the sound pressure levels in the frequencies above 1000 Hz, therefore, when summed logarithmically as in Equation (12), do not effect the perceived level of the flyover to the extent that the low frequencies do. This may be visualized by examining Equation (12) and what happens when the perceived levels in each one-third octave band of a typical flyover are summed logarithmically. If the sound pressure level in two of the bands are equal their sum is 3 PLdB higher than the level of either band alone. When there is a sound pressure level difference of 12 dB then the contribution of the lower level is only 0.3 PLdB when added logarithmically to the higher level.

This is what happens then at the distances where sound measurements are made in the community adjoining airports. The low frequency bands being relatively closer in sound pressure level to each other and at higher sound pressure levels than the frequencies above 1000 Hz contribute significantly to the energy and therefore the perceived level of

the flyover event. On the other hand, the frequencies above 1000 Hz have attenuated rapidly with distance from the source and are at much lower sound pressure levels. The high frequency bands therefore in this mix of sound pressure levels and frequencies contribute relatively little energy and therefore contribute little to the perceived level of the flyover event.

An additional consideration, is the relative house attenuation. According to SAE Aerospace Information Report 1081, this grand average of house attenuation ranges from 0.5 dB in the low frequency range below 125 Hz, 3.0 dB at 250 Hz, 4.9 dB at 500 Hz; 7.0 dB at 1000 Hz 8.2 at 2000 Hz and 9.2 dB in the 4 to 8 KHz frequency range. This provides more attenuation of the high frequencies than the low frequencies and further emphasizes the importance of the low frequencies generated by aircraft operation on the perceived (noisiness or loudness) level, PLdB experienced in one's home.

SECTION V

CONCLUSIONS

Because of the high degree of correlation found to exist between the perceived level, PLdB (Equations 11 and 12) engineering calculation procedure and the human judgement results for a diverse mix of aircraft sounds it is concluded:

- That PLdB (Equation 11 and 12) offers a new and simple engineering calculation procedure for determining the perceived level of the sounds associated with aircraft operations.

- That the relationship between the perceived level of sound and the physical nature of sound is an energy relationship dependent upon the pressure squared and the frequency squared as expressed in Equations (11) and (12).

- That the perceived level, PLdB, in each one-third octave band equals:

$$10 \ \mathrm{Log}_{10} \left[\frac{P \ uB}{.0002 \ uB} \quad \frac{f(Hz)}{1000(Hz)} \right]^2$$

- That the perceived level, PLdB, of an aircraft flyover or any sound equals:

$$10 \ \mathrm{Log}_{10} \left[\text{antilog} \ \frac{PLdB_1}{10} + \text{antilog} \ \frac{PLdB_2}{10} \cdots + \text{antilog} \ \frac{PLdB_N}{10} \right]$$

  or the logarithmic sum of the perceived levels calculated in each one-third octave band.

- That the perceived level of impulsive sound such as that of a sonic boom and steady-state sounds such as experienced by persons in their homes during aircraft operations is shown to be directly related to the pressure squared and the frequency squared or an energy relationship.

- That the absolute perceived level calculated by an engineering calculation procedure is a function not only of the energy relationship to pressure squared and frequency squared but also to the two reference levels selected for pressure and frequency, i.e. 0.0002 dynes/cm^2 and 1000 Hz as in PLdB (Equations 11 and 12), PNdB, dB(A) etc. When 3150 Hz is used as the standard frequency, as in PLdB (Mark VII) with 0.0002 dynes/cm^2 as the reference pressure, then the absolute perceived level calculated will be 10 PLdB lower, for this reason alone, or 20 Log$_{10}$ of the difference in standard frequencies selected for the psychophysical system.

- That a new psychophysical system has been developed and verified for psychoacoustic work consisting of the following steps:

1. The perceived level in dB or PLdB of a sound is equal to its sound pressure level in flat or unweighted dB at the standard frequency chosen which is 1000 Hz.

$$PLdB = 20 \; Log_{10} \left[\frac{P(uB)}{0.0002(\mu B)} \quad \frac{f\ 1000\ (Hz)}{1000\ (Hz)} \right]$$

2. The perceived level, PLdB of a sound measured in each one-third octave band is equal to the above equation with frequency f equal to the value of the mid-frequency of the one-third octave band. This simplifies to the following relationship when 1000 Hz is chosen as the standard frequency:

$$PLdB = dB - 60 + 20 \; Log_{10} \; f(Hz).$$

Where dB is the sound pressure level measured in flat or unweighted dB and f is the mid-frequency of the one-third octave band measured.

3. The perceived level of the sounds associated with an aircraft flyover or any other similar sound exposure is equal to the logarithmic sum of the perceived levels determined in each one-third octave band.

$$PLdB = 10 \; Log_{10} \left[\text{antilog} \frac{PLdB_1}{10} + \text{antilog} \frac{PLdB_2}{10} \ldots + \text{antilog} \frac{PLdB_N}{10} \right]$$

4. The PLdB determined by the above method PLdB (Equations 11 and 12) may be further corrected for duration, and tone if desired, as presently done in Part 36 of FAA regulations to provide EPLdB (Equations 11 and 12).

SECTION VI

REFERENCES

1. Stevens, S. S., "PROCEDURE FOR CALCULATING LOUDNESS: MARK VI" J. Acoust. Soc. Am. 33, 1577-1585 (1961)

2. Kryter, K. D. and Pearsons, K. S., "SOME EFFECTS OF SPECTRAL CONTENT AND DURATION ON PERCEIVED NOISE LEVEL" J. Acoust. Soc. Am. 35, 866-883 (1963)

3. Stevens, S. S., "PERCEIVED LEVEL OF NOISE MARK VII AND DECIBLES (E)", J. Acoustical Soc. of Am., Volume 51, No. 2 (Part 2), February 1972.

4. Higgins, T. H. and Carpenter, L. K., "A POTENTIAL DESIGN WINDOW FOR SUPERSONIC OVERFLIGHT BASED ON THE PERCEIVED LEVEL, PLdB AND GLASS DAMAGE PROBABILITY OF SONIC BOOMS", Department of Transportation, Federal Aviation Administration, Report No. FAA-RD-73-116, July 1973.

5. Higgins, T. H. and Sanlorenzo, E. A., "PSYCHOPHYSICAL TESTS OF POTENTIAL DESIGN/CERTIFICATION CRITERIA FOR ADVANCED SUPERSONIC AIRCRAFT" Department of Transportation, Federal Aviation Administration, Report No. FAA-RD-75-10, February 1975.

6. Zepler E. E. and Harel, J. R. P., "THE LOUDNESS OF SONIC BOOMS AND OTHER IMPULSIVE SOUNDS", Sound Vibrations (1965), pp. 249-256.

7. Higgins, T. H., "MEMORANDUM TO SUPERSONIC TRANSPORT DEVELOPMENT OFFICE", SS-230, February 21, 1968.

8. Higgins, T. H. and SST Staff Study, "HUMAN REACTION TO THE SONIC BOOM" April 23, 1968.

9. Higgins, T. H. and SST Staff Study "STRUCTURAL REACTION TO THE SONIC BOOM", April 23, 1968.

10. Higgins, T. H. and SST Staff Study "MINIMIZATION OF THE BOOM INDEX THROUGH DESIGN", May 23, 1968.

11. Kryter, K. D., et al, "SONIC BOOM EXPERIMENTS AT EDWARDS AIR FORCE BASE", National Sonic Boom Evaluation Office, Report No. NSBFO-1-67, July 28, 1967, Annex Band Table C-111-2.

12. Pease, C. B., "A NOTE ON THE SPECTRUM ANALYSIS OF TRANSIENTS AND THE LOUDNESS OF SONIC BANGS", The Journal of Sound and Vibration, Vol. 6, No. 3, 1967, pp. 310-314.

13. May, D. N., "THE LOUDNESS OF SONIC BOOMS HEARD OUTDOORS AS SIMPLE FUNCTIONS OF OVERPRESSURE AND RISE-TIME", Journal of Sound and Vibration Vol. 18, No. 1, September 8, 1971, pp. 31-43.

14. "NOISE CERTIFICATION CRITERIA AND IMPLEMENTATION CONSIDERATIONS FOR V/STOL AIRCRAFT", REPORT No. FAA-RD-75-190 November 1975.

SECTION VII

APPENDIX

APPENDIX A-1 and A-2

Measured takeoff and approach data: Peak sound pressure levels in 24 one-third octave bands for HU-1 Helicopter, Boeing 747, Beech 99 and Simulated Aircraft with strong tone.

APPENDIX B

Perceived levels calculated by four engineering calculation procedures and magnitude estimation results for four aircraft.

BOEING 747 (TURBOFAN, TAKEOFF)						BEECH 99 (TURBOPROP, TAKEOFF)					
1/3 OB Hz	A	B	C	D	E	1/3 OB Hz	A	B	C	D	E
50	65.5	61.3	64.1	59.6	50.3	50	61.2	57.0	53.2	49.3	47.1
63	66.3	62.3	57.0	50.2	49.0	63	60.8	54.7	52.4	48.5	46.7
80	63.9	60.0	58.2	53.7	48.7	80	76.8	72.4	68.8	64.2	61.7
100	60.8	57.2	58.2	52.9	45.9	100	90.5	86.2	82.3	77.4	75.7
125	72.8	68.7	70.5	65.2	57.0	125	69.5	65.7	60.1	56.0	55.2
160	82.0	73.1	75.1	69.8	65.8	160	72.2	67.3	60.9	58.1	57.3
200	67.3	63.4	60.6	55.6	51.3	200	68.7	64.6	64.7	58.6	54.4
250	71.3	67.3	62.2	57.5	56.0	250	62.1	57.9	55.4	51.0	47.7
315	79.6	75.7	70.9	66.2	63.9	315	65.5	64.7	61.6	57.4	53.9
[illegible]	64.7	60.8	58.3	53.8	49.8	400	69.9	66.3	57.4	54.3	56.1
500	59.1	55.3	56.2	50.7	44.7	500	58.1	53.7	52.9	48.5	43.5
630	55.7	52.3	50.0	46.5	41.3	630	52.9	50.5	44.9	40.8	40.5
800	55.7	51.8	47.5	43.3	41.8	800	50.6	46.5	42.2	38.5	38.0
1K	54.2	50.5	49.2	44.3	40.5	1K	52.1	48.5	43.7	40.5	39.5
1.25K	46.7	43.1	41.3	38.3	37.8	1.25K	47.9	43.0	39.2	36.8	36.6
1.6K	48.9	45.5	41.5	37.0	38.0	1.6K	45.9	42.2	37.4	36.8	36.8
2K	56.4	52.5	49.7	45.0	41.5	2K	45.3	41.2	37.4	35.5	36.2
2.5K	56.9	53.3	44.0	39.5	41.8	2.5K	44.4	41.0	36.9	35.3	36.0
3.15K	49.0	45.4	40.8	37.9	37.8	3.15K	45.7	41.1	37.5	36.1	36.6
4K	40.6	40.5	36.4	34.4	36.2	4K	42.5	40.4	35.8	36.7	36.2
5K	39.0	35.6	36.5	38.3	36.8	5K	43.4	40.8	35.9	36.3	36.3
6.3K	36.9	37.5	35.5	34.0	39.0	6.3K	43.1	40.2	36.9	35.0	36.0
8K	37.3	35.1	35.1	35.4	36.1	8K	42.5	40.3	35.2	35.3	35.9
10K	36.0	34.6	34.8	35.3	36.3	10K	43.4	38.8	35.2	35.1	35.6
PNdB	87.4	83.6	80.0	75.1	72.5	PNdB	89.9	85.6	81.6	76.9	75.2

PEAK SOUND PRESSURE LEVEL IN ONE-THIRD OCTAVE BANDS

APPENDIX A-1

Copy available to DDC does not permit fully legible reproduction

HU-1 HELICOPTER (APPROACH)						TURBOJET (WITH STRONG 2KHZ TONE)					
1/3 OB Hz	A	B	C	D	E	1/3 OB Hz	A	B	C	D	E
50	84.7	81.8	77.9	74.7	70.7	50	85.1	79.6	75.7	72.0	69.4
63	82.1	80.9	75.5	74.3	70.8	63	85.2	80.7	74.8	73.9	66.5
80	86.1	83.2	79.8	75.3	68.5	80	79.7	78.5	74.0	68.4	66.5
100	77.3	74.4	71.0	66.3	61.3	100	78.4	76.9	73.3	68.4	65.7
125	72.6	69.4	66.0	61.6	53.8	125	74.2	70.2	66.0	64.4	59.5
160	73.7	70.8	68.1	62.4	58.4	160	75.1	70.8	66.4	64.5	58.8
200	65.2	62.6	57.9	55.7	51.7	200	73.6	70.9	67.2	64.1	58.6
250	68.1	65.2	61.8	57.8	49.8	250	73.5	69.5	65.5	61.7	57.5
315	72.8	70.1	65.5	62.8	59.0	315	68.4	66.2	62.0	58.6	54.0
400	65.7	63.8	59.1	56.4	52.7	400	69.8	64.1	59.6	56.0	52.3
500	66.8	63.2	60.0	54.8	53.6	500	67.7	62.2	57.5	54.9	50.5
630	68.6	64.5	60.8	57.6	48.4	630	66.5	62.0	57.1	54.2	50.3
800	59.2	56.5	52.5	49.4	40.4	800	63.3	59.7	55.3	52.7	49.0
1K	53.4	51.8	46.3	45.4	46.9	1k	61.0	56.0	52.3	48.4	45.5
1.25K	48.2	47.3	42.3	40.7	37.7	1.25k	57.8	53.0	48.9	45.2	42.6
1.6K	46.9	44.0	40.0	38.6	36.9	1.6k	57.5	53.0	49.3	45.7	42.8
2K	48.9	46.5	42.3	40.6	37.3	2k	70.0	68.2	64.3	60.4	57.5
2.5K	47.4	44.3	39.8	38.4	35.9	2.5k	58.0	54.7	50.6	47.2	44.0
3.15K	48.0	44.8	39.6	40.2	36.4	3.15k	55.6	51.8	47.2	43.3	41.1
4K	42.8	40.9	36.5	40.3	34.8	4k	53.9	49.4	45.5	41.6	40.5
5K	43.7	39.1	41.6	37.7	35.7	5k	56.0	51.3	47.9	44.2	40.8
6.3K	42.9	39.0	36.8	41.1	35.3	6.3k	55.0	49.5	46.3	42.2	41.8
8K	48.0	35.6	35.6	35.7	35.2	8k	53.1	47.8	45.7	40.8	39.6
10K	41.0	34.8	35.6	36.2	34.4	10k	52.0	46.0	43.4	39.2	38.1
PNdB	88.5	85.2	81.0	77.1	71.8		91.7	88.4	84.2	80.4	76.9

PEAK SOUND PRESSURE LEVEL IN ONE-THIRD OCTAVE BANDS

APPENDIX A-2

Copy available to DDC does not
permit fully legible reproduction

APPENDIX B. PERCEIVED LEVELS CALCULATED BY FOUR ENGINEERING CALCULATION PROCEDURES AND MAGNITUDE ESTIMATION RESULTS FOR FOUR AIRCRAFT

AIRCRAFT	LEVEL	Log_{10} MAGNITUDE ESTIMATION RESULTS *	PLdB EQUATIONS (11) & (12)	PLdB (MARK VII)	PNdB	dB(A)
Boeing 747	E	.9	62.7	65.5	72.5	59.8
Boeing 747	D	.9	63.0	67.6	75.1	62.7
Boeing 747	C	1.0	66.3	72.3	80.0	67.6
Boeing 747	B	1.2	69.9	74.7	83.6	71.4
Boeing 747	A	1.3	73.6	78.3	87.4	75.3
Beech 99	E	.6	61.1	65.7	75.2	59.4
Beech 99	D	.7	62.3	67.1	76.9	61.9
Beech 99	C	.8	65.1	71.4	81.6	65.8
Beech 99	B	.9	68.3	75.5	85.6	70.5
Beech 99	A	1.1	73.2	79.7	89.9	74.4
HU-1 Helicopter	E	.9	61.1	65.4	71.8	58.1
HU-1 Helicopter	D	.9	64.7	69.5	77.1	62.7
HU-1 Helicopter	C	1.1	66.2	72.4	81.0	66.1
HU-1 Helicopter	B	1.1	69.4	76.0	85.2	70.0
HU-1 Helicopter	A	1.2	72.7	78.9	88.5	73.1
V/STOL Simulation	E	1.0	67.3	68.5	76.9	61.8
With Strong Tone	D	1.1	69.7	71.5	80.4	65.2
With Strong Tone	C	1.2	73.7	75.2	84.2	68.8
With Strong Tone	B	1.4	77.2	78.3	88.4	72.9
With Strong Tone	A	1.4	80.8	81.6	91.7	76.0

*Mean of 35 Magnitude Estimation Judgements for Each Flyover.